winSMITH: A computerized Smith chart

By Harold Kinley

The Smith chart is not used by land mobile radio technicians in performing their routine duties. However, understanding transmission lines and impedance matching *is* valuable to all who work with radio frequency equipment. The use of the *win*SMITH computerized Smith chart provides an excellent insight into transmission lines and matching networks. A few examples will serve to illustrate just how useful this tool can be. (Sourcing is given at the end.)

Figure 1 below is a screen snapshot of the *win*SMITH computer program. Here, a pi matching network is used to match a load consisting of a series resistor of 120Ω and an inductive reactance of 37Ω (120 + *j*37) to 50Ω.

Navigating in the program

First, a few notes about the screen snapshot. All of the available components are shown as buttons on the tool bar. In the *insert* mode, you can place a component on the schematic by simply clicking on the desired component button on the tool bar. In the insert mode, the new component will be placed just to the left of the selected component. The selected component is the one in the boxed area. If the program is not in the insert mode, the selected component will be replaced with the desired new component.

The value of the selected component is shown in the box just below the schematic. In Figure 1, the selected component is C_1. The values of the components are: C_1 = 25pF, L_1 = 50nH and C_2 = 25pF. The dotted circle around the center of the chart represents the constant VSWR circle. This feature can be turned on or off as desired. This VSWR circle is set to a VSWR of 1.5:1. (It can be set to any desired value.) On the chart, the "X" represents the impedance at the load (output of the circuit at the right) and the "O" represents the impedance at the input to the circuit at the left. If the "O" is highlighted with the mouse pointer, the "O" and the connecting arc will turn yellow, and several parameters will be listed in the top right corner of the screen.

These parameters are: Z (complex impedance), Y (complex admittance), S (S-parameter, S_{11}, or return loss in decibels and the reflection angle), G (gamma, or reflection coefficient and reflection angle), V (VSWR) and F (frequency). As shown, the VSWR is almost 3:1, and so the pi network must be tuned to place the "O" directly over the center (origin) of the Smith chart. Once the circle is placed over the origin of the Smith chart, the input impedance to the pi network will be 50Ω. This is the reference impedance shown under "Terminations" at the left of the screen. Stated another

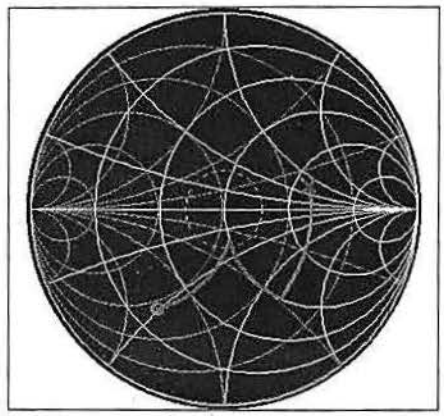

Figure 2. Capacitor C_2 is selected and tuned down to about 12.8pF. This causes the arc representing the inductor, L_1, to fall on the 50Ω constant resistance circle. *See text.*

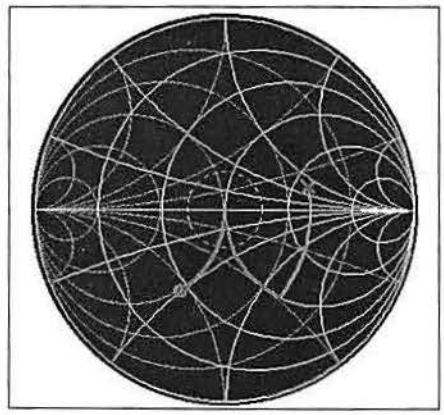

Figure 3. Inductor L_1 is selected and tuned to about 71.7nH so that the arc just passes through the origin of the Smith chart. *See text .*

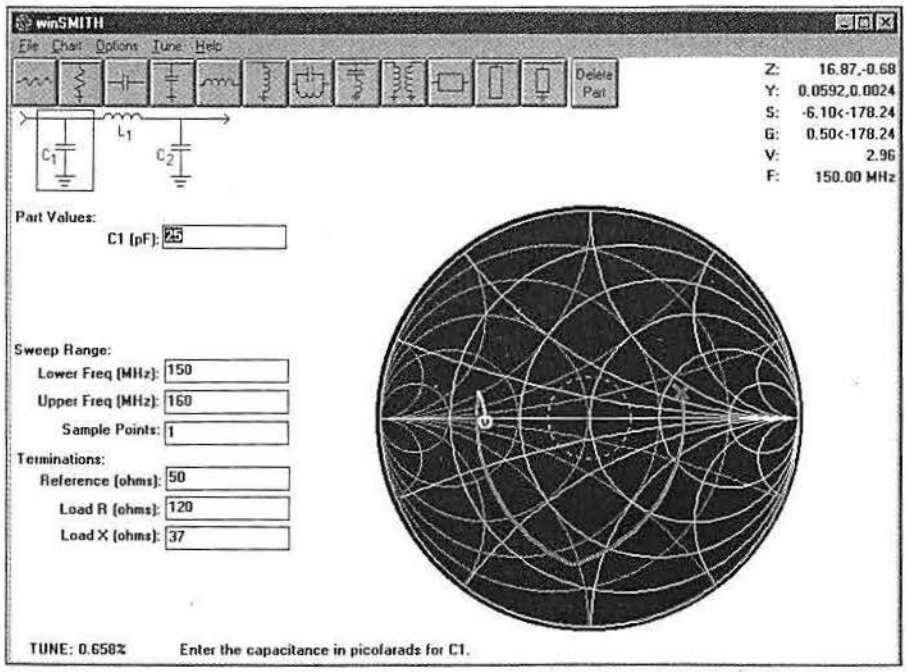

Figure 1. A screenshot of *win*SMITH 2.0 computerized Smith chart program. Here, a pi impedance-matching network is used to match an impedance of 120 + *j*37Ω to a 50Ω system impedance. The "X" marks the location of the load impedance on the chart, while the impedance at the input to the pi network (on the left of the circuit) is denoted by the "O" highlighted in yellow. At this point, the values for the pi network are: C_1 = 25pF, L_1 = 50nH and C_2 = 25pF. *See text for more details.*

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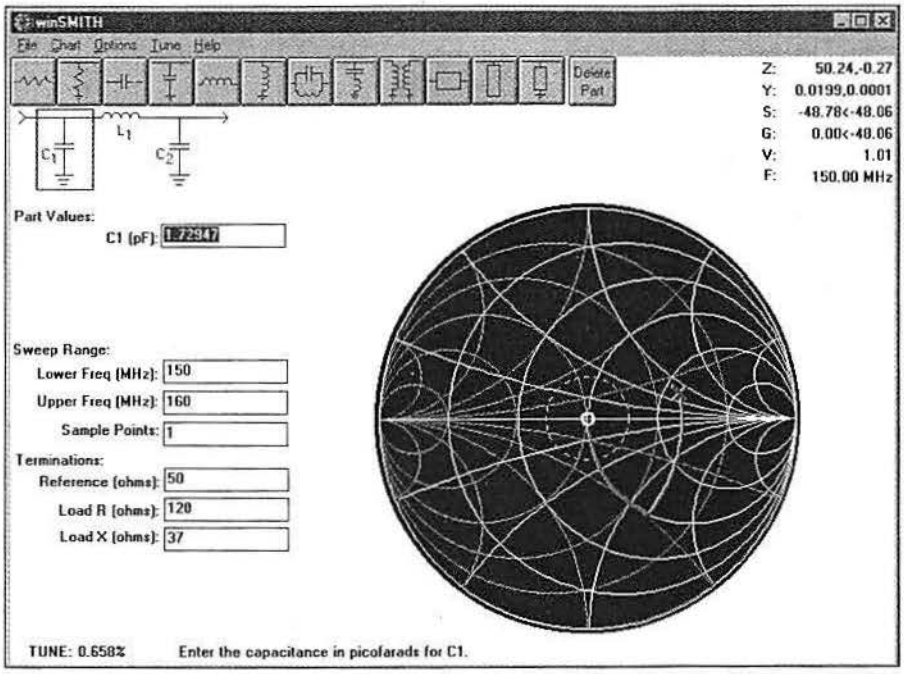

Figure 4. Capacitor C_1 is selected and tuned to about 1.7pF so that the "O" is positioned directly over the origin of the Smith chart. As shown in the upper right corner, the impedance at the input to the matching network is now $50.24 - j0.27\Omega$. This is a close match to the 50Ω system impedance, with just a fraction of capacitive reactance. The VSWR at this point is 1.01:1, a good match indeed.

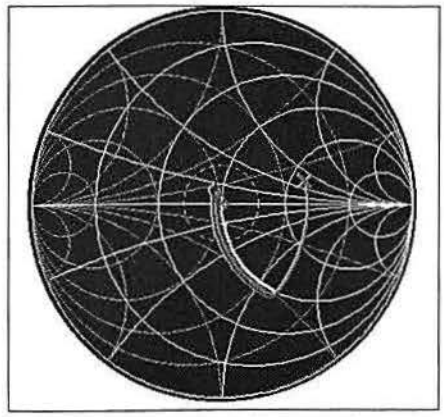

Figure 5. Here, three plots are shown to cover the frequency range of 150MHz to 160MHz. One plot is for 150MHz, one is for 155MHz and another is for 160MHz. As shown, all of these plots fall well within the 1.5:1 VSWR circle, and thus the matching network would effect a good impedance match at all of these frequencies.

way, the input impedance will be equal to the reference impedance when the circle is positioned directly over the origin of the Smith chart. The reference impedance can be set to other values of system impedance as well.

Note that the sweep range can be set from a minimum frequency to a maximum frequency with a number of sample points set by the user. If three sample points are specified, then the minimum frequency, maximum frequency and a center frequency would be plotted on the Smith chart. As shown on the screen, the sweep range is from 150MHz to 160MHz with only one sample point at this time. Because only one sample point is

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Sample Data

Freq (MHz)	Impedance	Admittance	S11	Gamma	VSWR
150	50.10,-0.24	0.0200,0.0001	-51.67<-66.33	0.00<-66.33	1.01
155	48.12,2.95	0.0207,-0.001	-28.95<120.81	0.04<120.81	1.07
160	46.27,6.22	0.0212,-0.002	-22.48<117.21	0.08<117.21	1.16

150 | Save To File | Print | Help | Close

Figure 6. (Above) By selecting the OPTIONS menu and then VIEW CALCULATED DATA, this chart is brought up on the screen. This chart lists the various parameters at all the plotted frequencies.

Figure 7. (Right) Instead of using a single load impedance at all of the frequencies of interest, you can specify a separate load impedance at each plotted frequency. Selecting VIEW LOAD TERMINATION DATA under the OPTIONS menu allows a different load impedance to be entered for each frequency to be plotted. To activate this, simply select USE LOAD TERMINATION DATA under the OPTIONS menu. *See text.*

Complex Load Data

	Frequency (MHz)	Resistance	Reactance
Point #1:	150	120	37
Point #2:	160	120	39.46
Point #3:	0	0	0
Point #4:	0	0	0
Point #5:	0	0	0
Point #6:	0	0	0
Point #7:	0	0	0
Point #8:	0	0	0
Point #9:	0	0	0
Point #10:	0	0	0
Point #11:	0	0	0
Point #12:	0	0	0
Point #13:	0	0	0
Point #14:	0	0	0
Point #15:	0	0	0

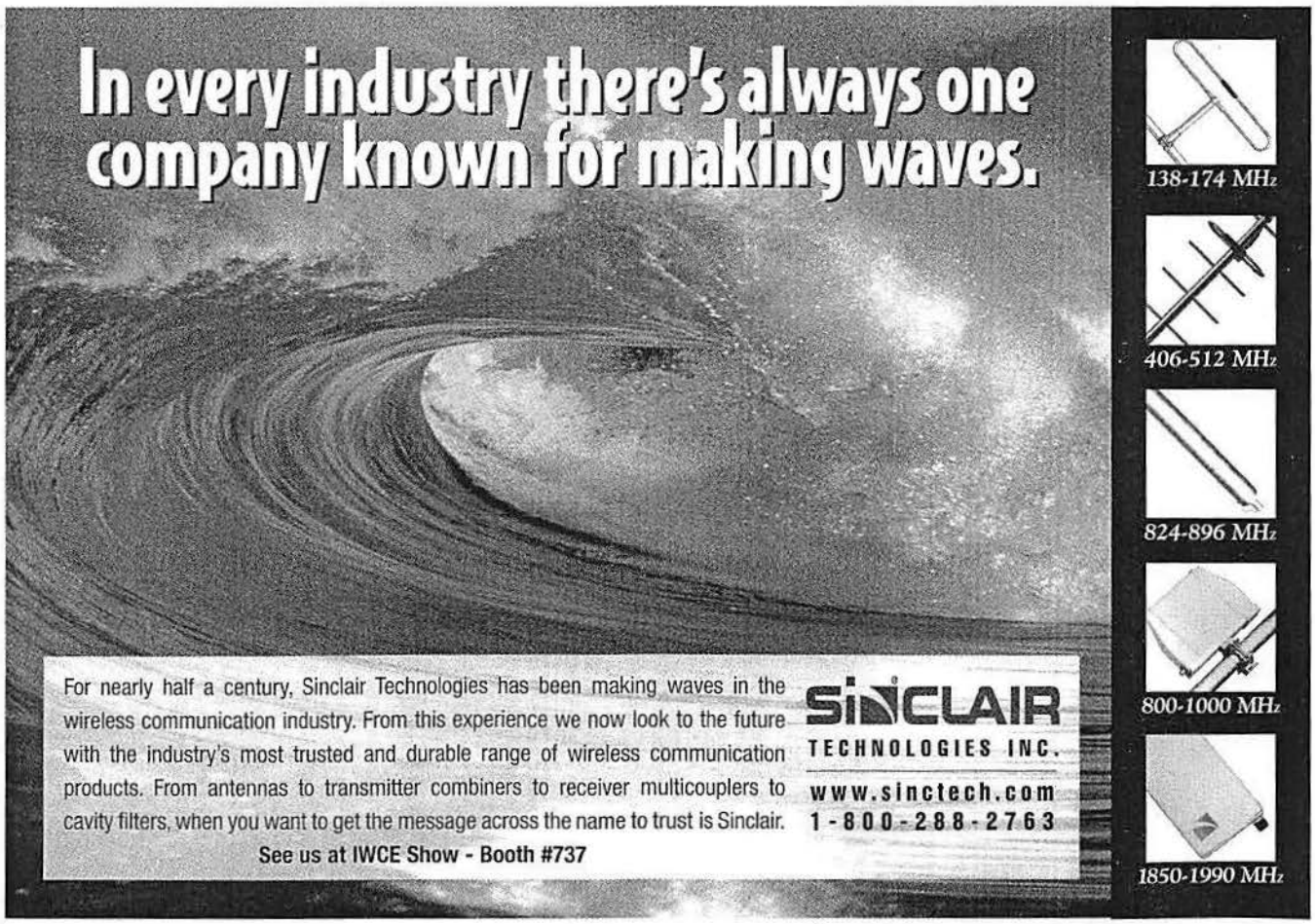
Load From File | Save To File | Help | Close

specified, it will be 150MHz.

First, we will work to get the circle over the origin of the Smith chart at 150MHz. Notice the three connected arcs on the Smith chart. Each of these arcs represent one of the components of the pi network. The arc connected to the "X" represents the capacitance, C_2. The center arc represents the inductor, L_1.

The final arc, connected to the circle, represents the capacitance, C_1.

So, to meet the objective of matching the load to 50Ω, we will have to tune the components in the pi network so that the circle is directly over the origin of the Smith chart. With *win*SMITH, it is possible to have either the admittance grid or the impedance grid turned on—or both. Notice that, in the example, we have both the admittance grid and the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impedance grid turned on. It is helpful to see both the impedance and admittance grids to tune a network for proper impedance matching. The brightest grid is the impedance grid, while the dimmer grid is the admittance grid. Note that the impedance grid is composed of constant resistance circles and constant reactance arcs. Conversely, the admittance grid is composed of constant conductance circles and constant susceptance arcs.

To tune a component, we must first select it and, with the component box highlighted, press either the PAGE UP or the PAGE DOWN button to respectively increment or decrement the component value. To increase or decrease the *rate of change*, press F7 or F9 respectively. In this example, starting with C_2, we press the PAGE DOWN button until the capacitance is about 12.8pF. At this point (see Figure 2 on page 20), the arc representing the inductor (L_1) lies on the 50Ω constant resistance circle. Next, L_1 is selected, and the value is adjusted to about 71.7nH so that the arc just passes through the origin (see Figure 3 on page 20). Next, the input capacitor, C_1, is selected and adjusted until the circle is placed directly over the origin of the Smith chart (see Figure 4 on page 22). At this point, the capacitance of C_1 is about 1.7pF.

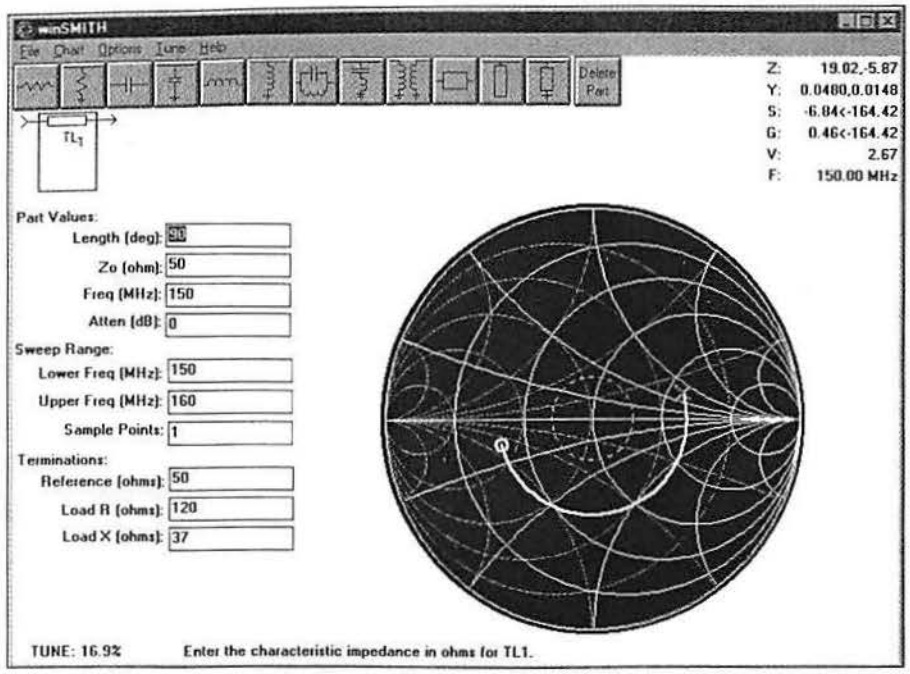
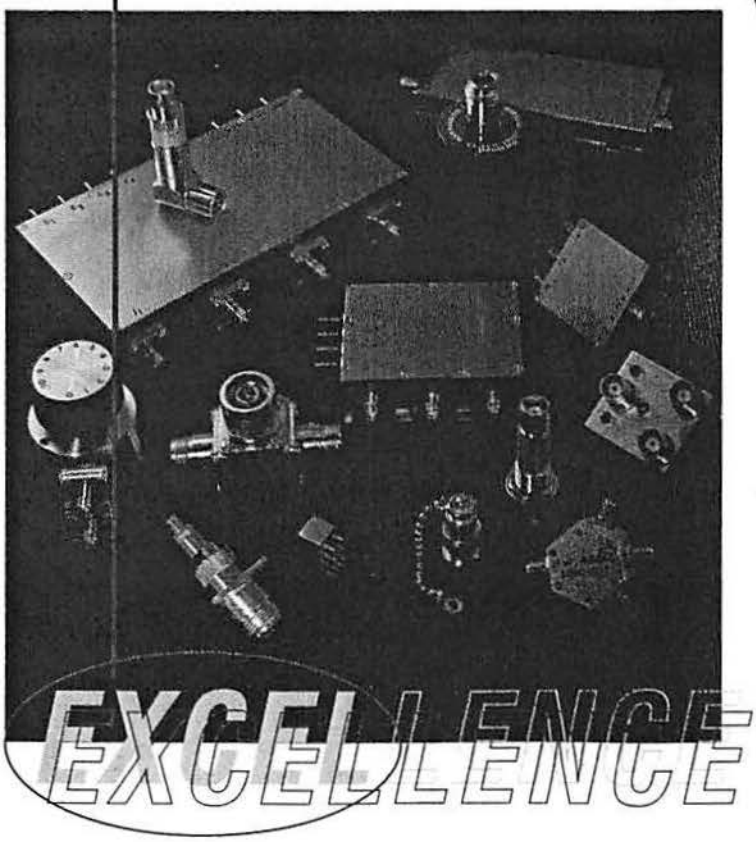


Figure 8. When a transmission line section is used (whether series or shunt), we must enter the length of the line, the characteristic impedance, the frequency of operation and the line loss. Here, a λ/4, or 90°, section of transmission line is connected to the load impedance (120 + *j*37Ω). The section of transmission line transforms the impedance from the "X" to the "O," representing one-half revolution around the Smith chart. The new impedance is shown in the upper right corner (19.02 – *j*5.87Ω).

Now, looking at the data in the upper right corner, we see that the impedance is 50.24 – j0.27, close to 50Ω, with just a small fraction of capacitive reactance.



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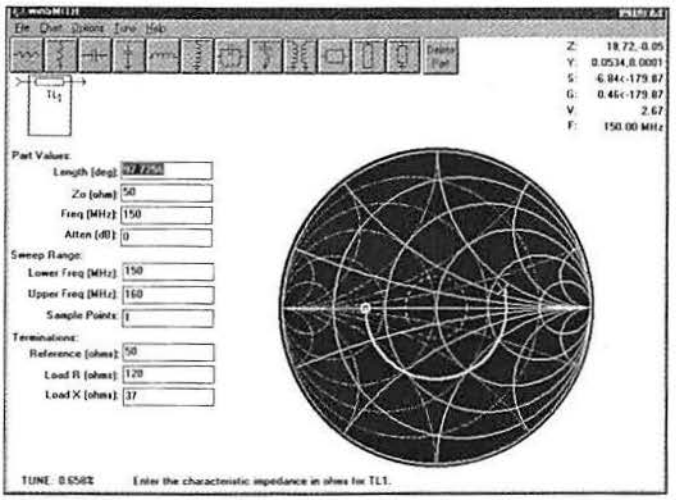

Figure 9. Here the transmission line of Figure 8 is lengthened until the circle is located on the horizontal (pure resistance) axis. As shown in the upper right corner, the impedance at this point is $18.72 - j0.05\Omega$. The reactive component is practically zero, leaving only a pure resistance. Thus, a reactive component can be tuned out by simply changing the length of the transmission line between the load and source.

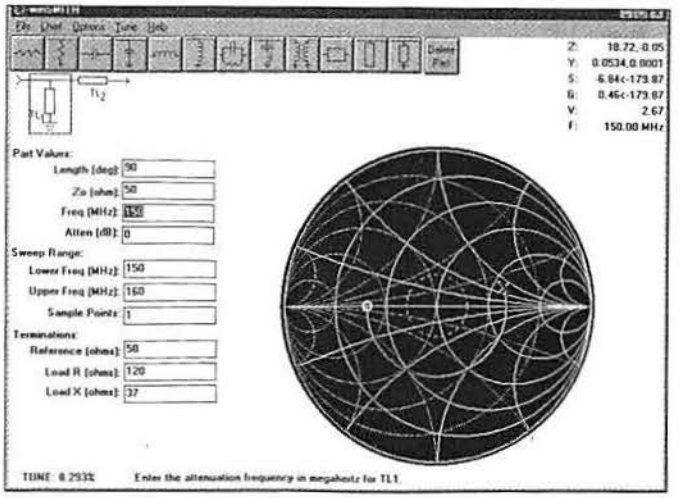

Figure 10. To effect an impedance match, a shorted stub is added to the input side of the series-connected transmission line. As shown, nothing on the Smith chart changed from Figure 9. When a new section of transmission line is added to the circuit, it is initially set to 90°, or $\lambda/4$. Because this stub is shorted on the far end, it reflects an open circuit at the end connected to the transmission line. Thus, the open circuit has no effect when connected across the line. If the length is changed from 90°, or $\lambda/4$, it will affect the impedance. *See Figure 11 below.*

Remember, this is at a frequency of 150MHz. If we want to know the response over the bandwidth of 150MHz to 160MHz, we can enter these figures into the sweep range and take three samples: lower, middle and upper frequencies. Figure 5 on page 21 shows just the Smith chart graphic for the three different frequency plots. Note that the input impedance of all three plots lies within the 1.5:1 VSWR circle. So, the resulting match at all frequencies would be quite acceptable. If necessary, the components of the pi network could be fine tuned to the center frequency to reach a compromise at the upper and lower frequencies.

By selecting the OPTIONS menu and then VIEW CALCULATED DATA, the chart in Figure 6 on page 24 is displayed. This chart lists the various parameters for each frequency. Another option from the OPTIONS menu is to USE LOAD TERMINATION DATA. Instead of using a single load impedance (resistive and reactive component) for all frequencies, a separate load impedance can be specified for each frequency to be plotted. Figure 7 on page 24 shows the table that is used to input the load impedance for each frequency to be plotted. This table can be viewed by selecting the OPTIONS menu and then VIEW LOAD TERMINATION DATA.

Let's look at another example using a transmission line to provide an impedance match. Using the same load impedance as specified in the first example ($120 + j37$), we will explore what happens when we use different lengths of transmission line. Then we will effect an impedance match using a transmission line stub placed at the proper point on the transmission line.

Refer to Figure 8 on page 26. Here, a $\lambda/4$, or 90°, section of transmission line is connected to the load. The arc on the Smith chart has moved halfway around the chart. Remember, $\lambda/2$ represents a full revolution around the Smith chart,

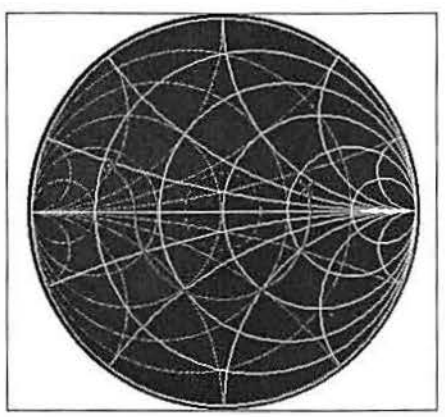

Figure 11. Here, the shorted transmission line stub shown in Figure 10 has been shortened to 24.6°. Notice the difference between this plot and the plot in Figure 10. The shorted stub now has affected the impedance, and the plot has changed.

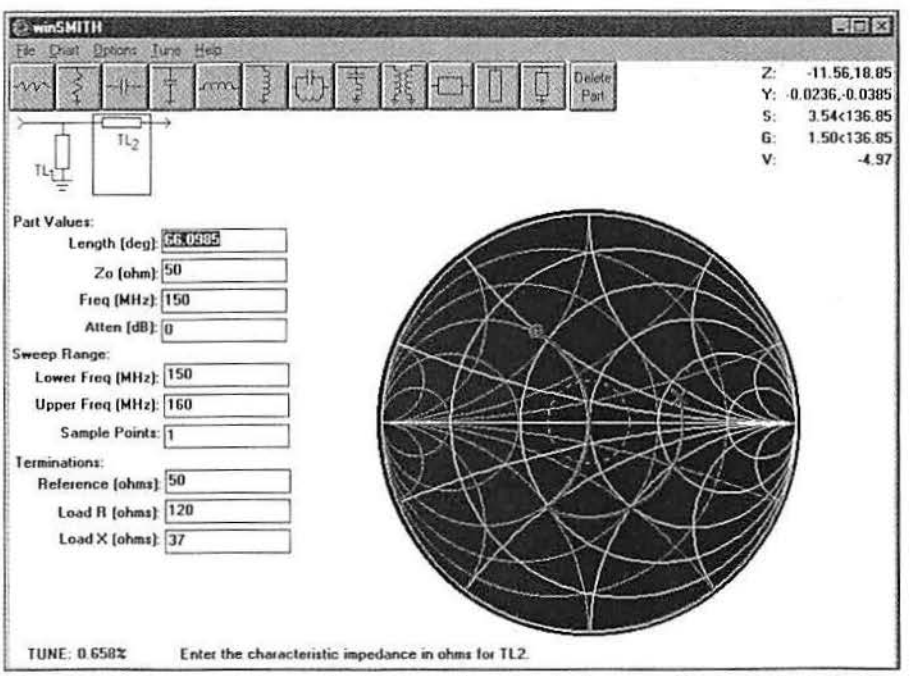

Figure 12. With the main transmission line selected, it is decreased in length to bring the arc representing the shorted stub to pass through the origin of the Smith chart. All that remains is to select the shorted stub and tune its length to place the circle directly over the origin of the chart. *See Figure 13 on page 29.*

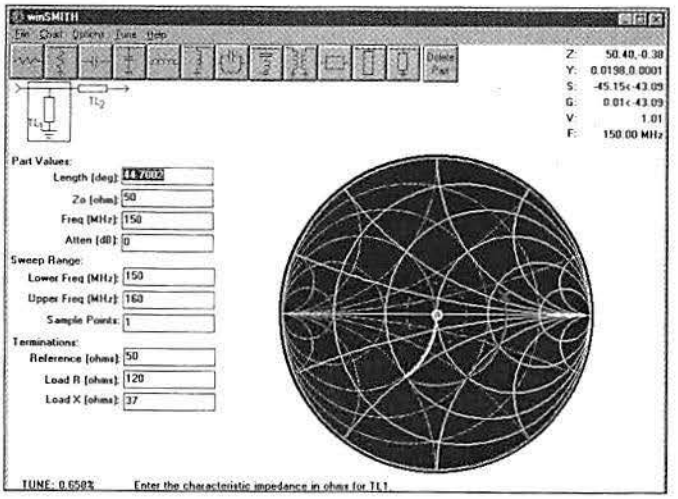

Figure 13. When the shorted stub is tuned to a length of 44.7° the circle is positioned directly over the origin of the chart and the impedance of the load is matched to the 50Ω system impedance. As shown in the upper right corner the impedance at the input is 50.4 – j0.38Ω, an excellent match.

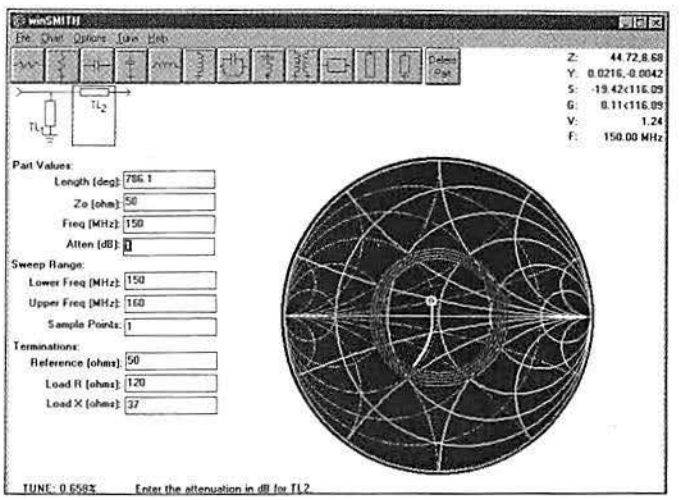

Figure 14. By adding two wavelengths to the main transmission line of Figure 13 and 1dB of loss the plot makes four complete revolutions around the Smith chart and the 1dB of transmission line attenuation has affected the impedance match. The circle is no longer centered over the origin. See text for details on how this can be handled.

and repeats for each additional λ/2. If we simply wanted to remove the reactive component from the load, we could lengthen the transmission line until the circle is positioned directly over the horizontal axis. Any point along the horizontal axis represents a pure resistance, no reactance. In Figure 9 on page 28, the transmission line has been lengthened to 97.6° so that the reactive component is removed and the input impedance is a pure resistance of about 18.7Ω. This still lies far outside the 1.5:1 VSWR circle, and so it isn't within our desired VSWR limit.

Let's add a shorted stub to the input side of the transmission line (see Figure 10 on page 28). A new transmission line (or stub) is always set to a length of 90°, or λ/4, initially. It is important to set all the transmission line parameters to the correct value. We are assuming a 50Ω line with no loss at a frequency of 150MHz. The λ/4 shorted stub has been connected to the input side of the transmission line—but nothing happened. The arc didn't change. This is because a λ/4 shorted transmission line will appear as an open circuit at the other end. So, the end connected to the input

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of the transmission line is open and has no effect on the impedance.

Now, let's change the length of the stub to see how it affects the input impedance. To change the stub length, we click on the stub (TL_1) and use the PAGE DOWN key to decrease the length while observing the arc. Figure 11 on page 28 shows the arc at a stub length of 24.6°. Next, we select the main transmission line and decrease its length until the arc connected to the circle passing through the origin on the Smith chart (see Figure 12 on page 28). Now, all we have to do is fine-tune the length of the stub until the circle is positioned directly over the origin on the Smith chart (see Figure 13 on page 29). Note that the impedance at this point is $50.4 - j0.38\Omega$—nearly a perfect match to a 50Ω system impedance.

You might note that the length of the main transmission line in the previous example ended up at only 66.1°. This is quite impractical in reality. Remember, the line can be increased to a more practical length as long as the added length is a multiple of λ/2, or 180°. You might also note that we used a theoretically lossless transmission line in our example. If you know the loss of the transmission line that you are using, you can enter it into the transmission line parameters.

Let's see what happens if we add 2λ (720°) to the main transmission line used in the last example. Let's also assume that the cable has a total loss of 1dB (see Figure 14 on page 29). You will notice here that there are four complete circles around the origin. For each λ/2 there will be one complete revolution around the Smith chart. Because there are four complete λ/2 sections, there will be four revolutions around the chart. Also, notice that the final impedance point does not end up over the origin of the chart. Thus, the attenuation of the transmission line has affected the impedance match. We don't know how long the cable is going to be until we have adjusted the lengths to place the circle over the origin on the chart. And if we then go back and calculate the attenuation of the cable, based on the final length the impedance at the input will change. How do we get around this? One simple way is to determine the practical length of cable needed to connect the generator to the load. Insert that line into the schematic on *win*SMITH. Enter the line length and loss and the operating frequency. Then add a second line in series with the first. Do not change the length of the first line—let it remain unchanged throughout the whole impedance-matching process. Let the loss of the second series line be zero. Because the line will be short, it won't exhibit much attenuation, and such a small loss will not significantly affect our impedance match. The loss in the stub can be ignored because it will be short and exhibit little attenuation. The loss that is entered for the series transmission line will be the *total loss* in the line—not loss per hundred feet as specified in transmission line charts, etc. The small series section of line that we are tuning will not exceed λ/2 and the stub will not exceed λ/4, so the resulting attenuation of each line will not be significant.

The *win*SMITH computer program is capable of doing much more than we were able to show in the space limitations of this column. Many additional features exist that were not discussed. The program is an excellent educational tool as well as a practical tool. It is intuitive and easy to learn. It takes longer to describe the operations than it does to actually perform them. Some prior knowledge of the Smith chart is helpful but not absolutely necessary.

A companion video tape by Glenn Parker would be helpful to those who have no familiarity with the Smith chart but would like to learn.

The *win*SMITH 2.0 software is available from Noble Publishing, 4772 Stone Drive, Tucker, GA, 30084. Phone (770) 908-2320 or fax (770) 939-0157. You can visit their Web site at **www.noblepub.com** The cost of the program is $79 for version 2.0. Special pricing is available for upgrading from version 1.0.

Until next time—*stay tuned!* ■